Time-Course Gradient-Echo EPI of Localized Signal Enhancement in the Human Brain During Task Activation

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PURPOSE:

We demonstrate that time course, long-TE, gradient echo EPI is an effective tool in localizing, without the use of contrast agents, human brain function associated with task activation.

INTRODUCTION:

Blood is a unique source of physiological contrast in MRI due to its oxygenation-sensitive paramagnetic characteristics. Deoxyhemoglobin contains paramagnetic iron while oxyhemoglobin contains diamagnetic oxygen-bound iron (1). It has been demonstrated that the paramagnetic contribution of deoxyhemoglobin affects the susceptibility of whole blood (1-4). Microscopic B_0 field inhomogeneities within and around vessels are created by this susceptibility differential. A spin-echo is attenuated by dephasing due to diffusion of spins through field inhomogeneities while a gradient-echo is additionally attenuated by dephasing due to static field inhomogeneities, independent of diffusion.

Recent work demonstrates the sensitivity of gradient-echo imaging to blood oxygenation changes (3,5). Furthermore, preliminary success using gradient-echo EPI in observing signal changes in the visual cortex during photic stimulation has been reported (2).

METHOD:

Imaging was performed on a standard clinical GE 1.5 Tesla Signa system using either a 30.5 cm i.d. three-axis local gradient coil or a 33.0 cm i.d. prototype GE z-axis local gradient coil. A blipped, gradient-echo EPI pulse sequence, having an initial $\pi/2$ pulse and an effective TE, (kx, ky) = (0, 0), of 50 ms, was employed. Data acquisition time was 40 ms to acquire a 64 x 64 image. The FOV ranged from 20 to 24 cm. Slice thickness was 25 mm to ensure that the region of activation was completely contained in the slice. A series of up to 128 sequential images of the same plane in the brain was obtained using an inter-scan delay or TR of 2 to 3 s.

Each time course series was generally divided in time into three segments. During the first and last segment, the subject was instructed to remain completely relaxed. During the middle segment, the subject was instructed to perform the well-established sensory and motor cortex activation paradigm of touching each finger to thumb in a self-paced and repetitive manner. Fingers on one or both hands were used.

All post-processing was performed on a Sun SPARCstation 1+. Brain activity images were obtained by calculating the cross correlation between the time response of each voxel and the ideal response to the task activation. The cross-correlation calculation was performed for each voxel and displayed in an image array, termed the brain activity image. Voxel values that change in a manner temporally correlated to the finger movement activity had the highest values in the brain activity images. Plots of signal intensity versus image number from activated regions, demonstrating the temporal characteristics of the signal enhancement, were also made. The fractional signal change in the activated region was calculated from a 4-voxel volume in each image series using:

$$\%\Delta S = ((Sa - Sr) / Sr) \times 100$$

where $\%\Delta S$ is the per-cent change in signal, Sa is the averaged activated state signal, and Sr is the averaged resting state signal. The change in relaxation rate, ΔR_2^*, associated with task activation was calculated using the relationship (6):

$$-\ln(Sa / Sr) / TE = \Delta R_2^*$$

RESULTS:

A total of 24 experiments were performed on 6 healthy volunteers. An increase of 4.3% ± 0.3% in signal was observed in the areas functionally associated with the task during activation. The calculated ΔR_2^* during activation is $-0.8 \pm 0.1\ s^{-1}$.

The areas of signal enhancement correspond with regions known to be associated with the finger movement task. Figure 1 shows a typical plot of signal intensity versus sequential image number (TR = 2 s) from an ROI in the primary motor cortex contralateral to the hand performing the task. Finger movement takes place during the time between the vertical arrows. Preliminary results using spin-echo EPI show no significant signal enhancement during task activation.

CONCLUSIONS:

The observed increase in signal intensity in the activated region of brain is potentially explained qualitatively by findings that, during local brain stimulation, oxygen delivery to the activated region exceeds metabolic need (7). The overabundance of oxygen-rich blood leads to a decrease in the local oxygen extraction fraction, directly suggesting a local increase in blood pO_2 and a local decrease in the concentration of deoxyhemoglobin. Such a decrease in deoxyhemoglobin concentration decreases the vessel-tissue susceptibility differential, allowing increased spin coherence and thus increased signal. Time course gradient-echo EPI is a powerful new noninvasive tool for assessment of regional cerebral activation with high temporal and spatial resolution.

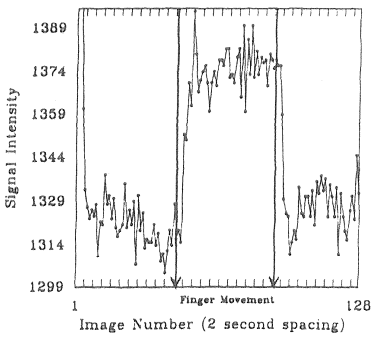

Figure 1

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